Relating Pull Forces and Power Consumption on Small Scale Autonomous Vehicles

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ABSTRACT : *With The Earth's Population Predicted To Reach Approximately 9 Billion People By 2050, Improvements In Technology Are Needed To Ensure A Stable Food Supply, While Reducing The Environmental Impact Of Traditional Agricultural Practices. Research Is Being Conducted On Small Scale Autonomous Vehicles And Their Abilities To Perform Agricultural Tasks, Such As Tillage And Planting. Many Benefits Could Arise From The Use Of Small Autonomous Vehicles Including Reduced Soil Compaction, Lower Energy And Material Inputs, Reduced Air Pollution, And Decreased Manual Labor.*
The feasibility of such vehicles is currently being investigated with the use of a small, tracked AgDrone. To better understand the capabilities of this machine, a series of static and dynamic pull tests were conducted using a load cell and a myRio data acquisition system. With this data, a relationship between pull force and power consumption was developed. This relationship provided much needed information on the AgDrone's ability to replace current large scale tractors, while increasing the efficiency of common production agriculture tasks. After the data was analyzed, it was determined that modifications to the AgDrone as well as farming implements and methods are needed before the AgDrone is able to replace large scale agriculture equipment.

I. INTRODUCTION

With the earth's population expected to reach 9 billion by 2050, increases in agriculture production will be a necessity. However, with this increase in production, the environmental impacts of farming must be minimized. One possible solution to these two issues is the utilization of small autonomous vehicles for farming operations, such as tillage and planting. Use of these smaller machines may provide many benefits over current agricultural practices.

Small autonomous vehicles can potentially reduce soil compaction, energy cost, material cost, pollution, and labor requirements. Research was conducted utilizing a small, tracked AgDrone to determine the current feasibility of using small autonomous vehicles to replace large machinery used to perform farming operations.

Testing was conducted to determine the pulling abilities of the AgDrone. The AgDrone was subjected to both static and dynamic pull tests to determine the maximum pull forces produced by the drone and the relationship to motor power consumption and ground speed. Force and power data was collected utilizing a myRio data acquisition system.

ASABE Standard D497.7 was then utilized to estimate draft force requirements for common farming practices. The estimated draft forces were then compared to the collected data to determine the feasibility of utilizing single row implements for farming applications with the AgDrone. Based on this comparison, suggested modification to the AgDrone design and current agricultural practices were suggested for future research.

II. LITERATURE REVIEW

The use of autonomous vehicles in production agriculture has been explored for some decades. Initial research has been conducted using various sizes of machines for a wide range of applications. Automation of large scale equipment for common agriculture tasks yielded successful results as far back as 1997. That year, a New Holland 2550 self-propelled windrower successfully mowed 40 ha (100 acres) of alfalfa. This was completed in "one continuous autonomous run". The next year, a 50 ha (120 acres) was also harvested [7].

Since that success, many smaller systems have been explored and evaluated for many different forms of agriculture. Chaoui and Sorensen discuss the constraints automated systems must have to be successfully applied to organic farming. These constraints include quality products, quality processes, minimizing traditional fossil fuel energy, justifiable in cost, labor reducing, and sized to fit specific tasks. Systems range from small, weeding robots, to autonomous animal feeders and housing units that relocate animals as needed to optimize animal and pasture health [4]. This helps illustrate the possibility for small, unique systems in niche

markets, as well as the opportunity to implement autonomous machines in larger, traditional production farms.

With the possibility for autonomous machines to transform traditionalproduction agriculture apparent, research has been conducted on various aspects of autonomous or robotic systems. Understanding how traditional implements interact with the environment is a critical step in introducing unmanned tasks into the traditionally labor intensive agriculture world. Armin, Fotouhi, and Szyszkowski discuss using an FEA method to accurately predict forces developed on a blade during soil interactions [1]. The successful results they express give added strength to the possibility of redesigning smaller implements for use with small scale autonomous vehicles. Traditionally, draft forces are calculated using the generic draft equation detailed in the ASABE standard ASAE D497.7, updated March 2011. However, as Askari and Khalifahamzehghasem discuss, measured forces in various scenarios may differ significantly from those calculated using the standard equation [3]. Therefore, this further demonstrates the need to use more advanced methods and updated testing to develop small scale implements and systems.

As with any agriculture machine, understanding power needs and power consumption is critical to developing an efficient, viable product. Mei, Lu, Hu, and Lee detail a power consumption monitoring method for a Pioneer 3DX robot. Their results show that the largest consumer of power for this system is the embedded computer, followed by motion, then microcontroller, and finally sensing instruments [6]. While the specific power consumption may vary for each system depending on the application of the machine and the internal components, the need for similar studies is an integral part in researching and transitioning to smaller, electrical machines.

With the majority of research being focused on determining the feasibility of small scale autonomous machines and their capabilities, some research is being conducted to better understand the economics of replacing traditional machines with smaller autonomous technologies. Goense, [5] as well as Toledo, Steward, Gai, and Tang [8], discuss the constraints and comparisons that must be made in order to implement new technologies into production agriculture. Producers must be able to justify the cost of new machines through fuel savings, time savings, or labor reductions. Understandably, any small scale autonomous vehicle must prove to be economically feasible in order to replace current large scale machines.

Based on research from more than 20 years ago to the analysis of current designs, the possibility of small scale autonomous machines replacing larger traditional machines is still being investigated as a solution to increasing agriculture output while minimizing resource input. Understanding the market potential, implement and power requirements, and the economic feasibility of such machines is critical to creating and implementing new technologies into production agriculture.

III. TEST PROCEDURE AND ESTIMATED DRAFT FORCES

Equipment A small, tracked AgDrone, as shown in Figure 1, was used throughout this test procedure. The AgDrone was equipped with a 24 volt dual motor system, powered by two 12 volt deep cycle Optimabatteries. These batteries were kept charged to full capacity for each round of testing. Current and voltage sensors within the AgDrone's motor systems were utilized to determine the power output of the two drive motors.

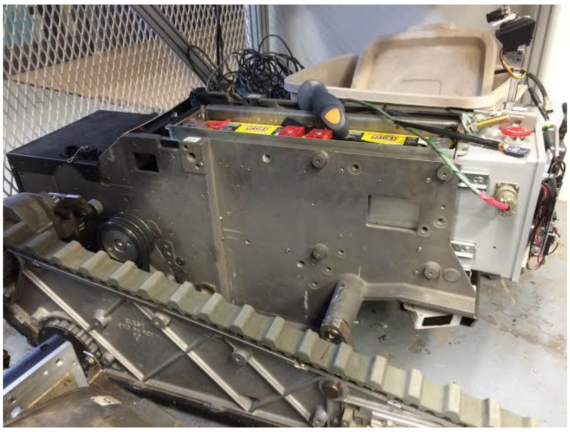


Figure 1. AgDrone use throughout experiment.

A s-type load cell, as shown in Figure 2, was equipped to the AgDrone to determine the observed draft forces. The load cell was rated for 500 pounds and delivered an output signal of 3.0016 mV/V. Figure 3illustrates how the load cell was attached to the AgDrone and shows the drawbar assembly, which housed the load cell. The eyebolt acted as the drawbar for the AgDrone and was connected to the load cell. The load cell was calibrated as described in the following section.

Figure 2. S-type load cell used to determine draft forces applied to the AgDrone.

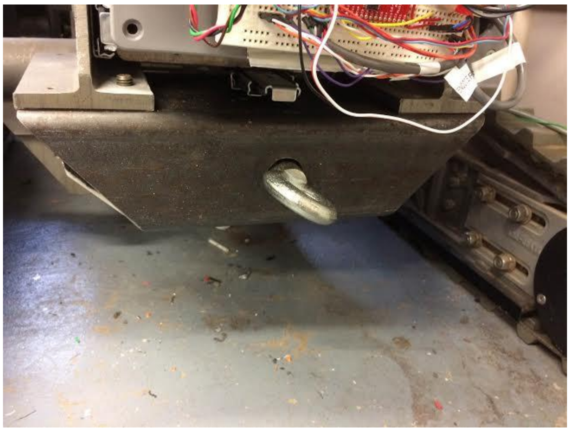


Figure 3. Drawbar assembly housing the load cell mounted to the AgDrone.

A National InstrumentsmyRio data acquisition system was utilized to acquire the desired data and control the functions of the AgDrone. National Instruments LabVIEW was used as the software interface for the myRio. Programs were developed in LabVIEW and deployed to the myRio to control the AgDrone and collect the desired data from the motor sensors and load cell. The myRio used throughout this experiment is shown in Figure 4.

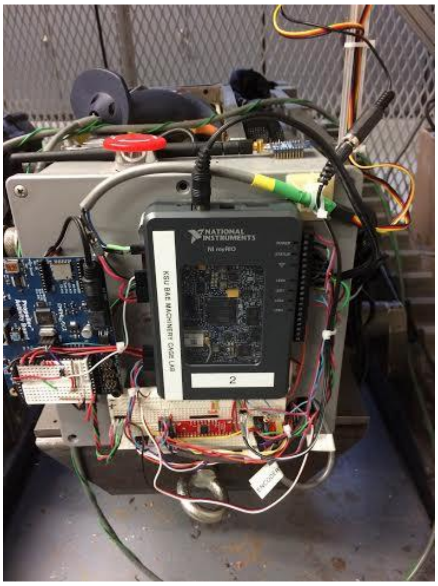


Figure 4. myRio data acquisition system used to collect data and control AgDrone functions.

The collected data was transmitted wirelessly to a computer by utilizing a Parallax Propeller Activity Board and a DigiXBee Pro S3B radio frequency module. CoolTerm was used to view the received data and save the data in a text file to later be manipulated in Excel. The Propeller Activity Board is shown in Figure 5.

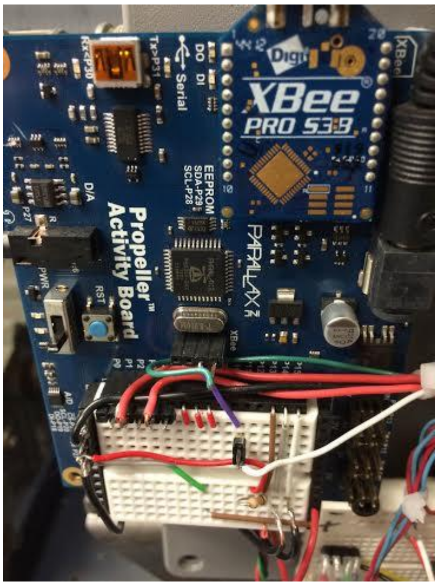


Figure 5. Propeller Activity Board and radio frequency module used to wirelessly transmit data collected by the mRio.

A Yamaha Grizzly 700 four-wheeler was utilized as a load sled for the dynamic pull tests. The four-wheeler brakes were used to vary the draft force applied to the AgDrone. The winch equipped to the four-wheeler was used to connect the two machines together.

Load Cell Calibration

The load cell used for this experiment was calibrated using an assortment of tractor weights and a 500 pound hoist. The tractor weights used were available in 40 pound and 100 pound sizes. The load cell was equipped with two eyebolts, one of which was attached to the hoist hook. Weights of 40 pounds, 80 pounds, 180 pounds, and 200 pounds were attached to the other eyebolt by a small, lightweight chain. The hoist cable was then retracted until the weights were no longer touching the ground. The cable was then allowed to stabilize before load cell output voltages were acquired. The load cell data was then exported from LabVIEW into an Excel spreadsheet. Load cell output voltages collected after the hoist cable had stabilized were then averaged. The averaged output voltages were then related to the weight of the attached tractor weights to develop a relationship between the voltage output and applied force. The resulting relationship was then utilized to convert output voltages observed during testing into observed force in pounds.

Test Procedure

Both static and dynamic pull test were perform by the AgDrone. The goal for both pull types was to determine the maximum pull force the AgDrone could produce. These pull forces were then related to the observed power consumption of each motor and the ground speed of the AgDrone.

Static Pull Test Procedure

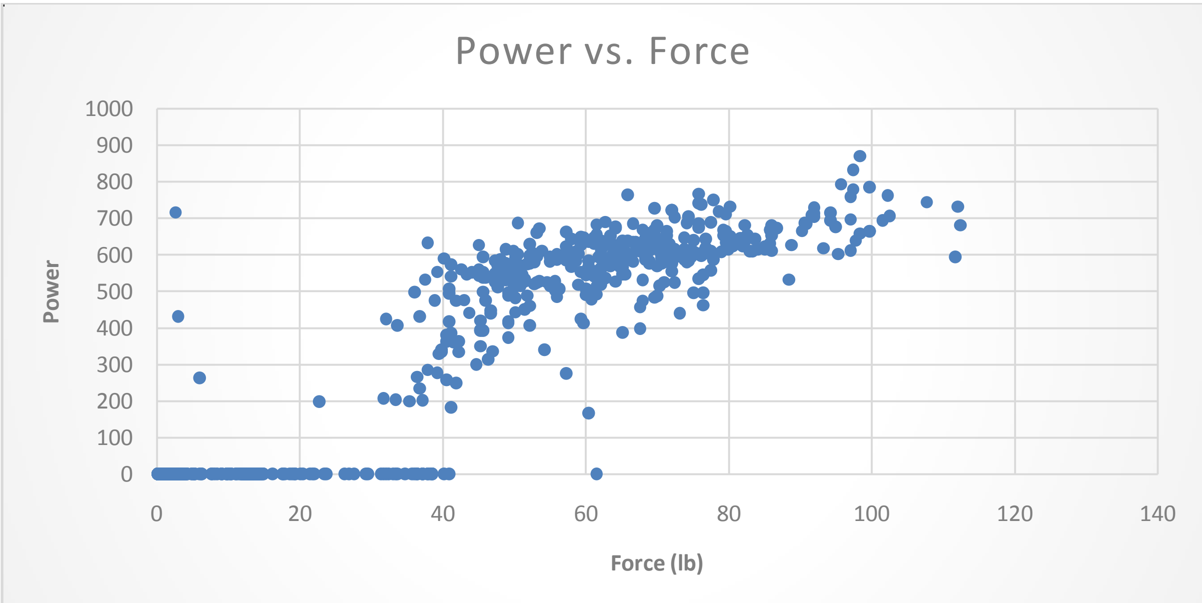
For this test, a chain was wrapped around a stationary pillar and attached to the AgDrone via the load cell eyebolt. The test was performed on a rough concrete surface to increase tractive efficiency. Slack in the chain was removed to avoid impulse forces on the load cell. The AgDrone was then operated at full speed for a 3 to 5 minute duration. Pull force and motor power consumption data was collected and interpreted.

Dynamic Pull Test Procedure

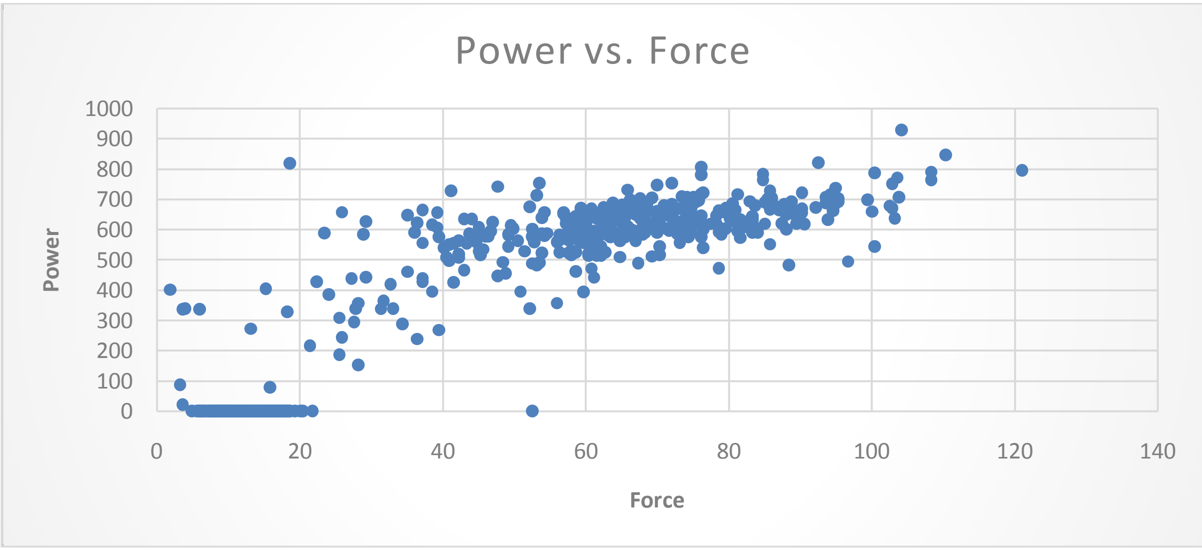
For the dynamic pull tests, a Yamaha Grizzly 700 four-wheeler equipped with a winch was utilized as a load sled. The four-wheeler's brake system was utilized to create various loading conditions. The AgDrone was attached to the four-wheeler via the load cell eyebolt and the winch hook. A straight, 15 foot test track distance was used throughout the experiment. The tests were performed on a rough concrete surface to increase tractive efficiency. As the AgDrone traveled down the test track, the brakes on the four-wheeler were applied at a constant rate to ensure that a constant force was applied. A stopwatch was used to measure the pull duration so that the average velocity of the AgDrone could be calculated. Pull force and motor power consumption were also recorded. Multiple trials, at different loads and speeds, were performed.

DATA

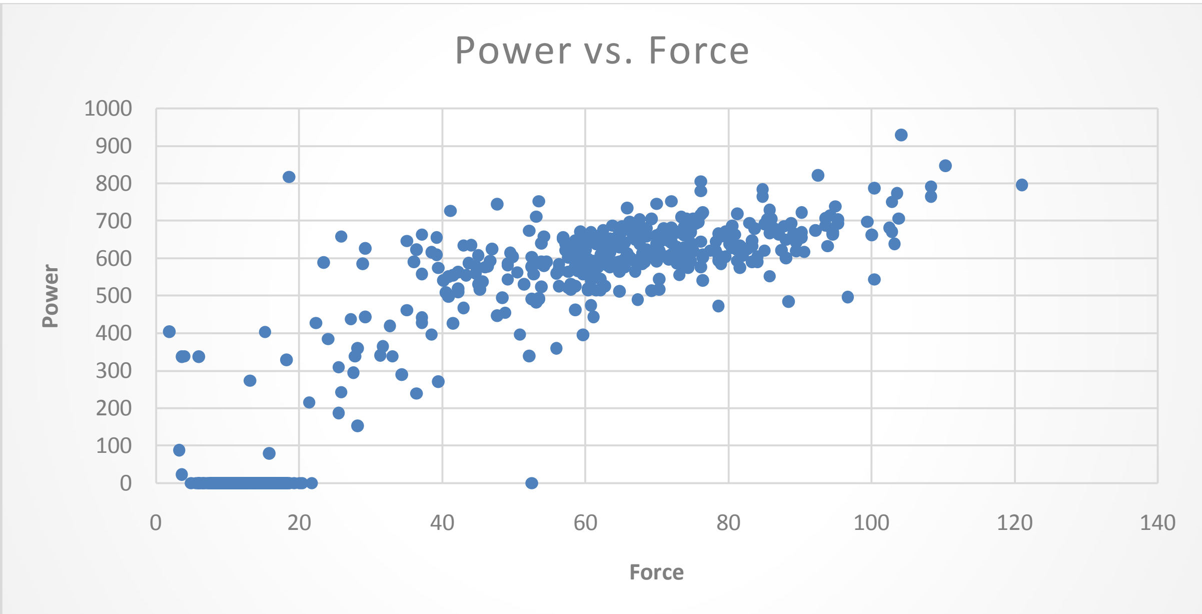
Data was collected and manipulated as discussed in the previous sections. Each trial is displayed below as a scatter plot. The trials include three tests conducted with constant braking force applied and two tests conducted with varying braking force applied throughout the pull. All graphs are displayed as Power versus Force. Force units are pounds (lb), while the power units are uncalibrated, unitless values. All recorded values, for the entirety of each trial, are displayed on the following graphs.



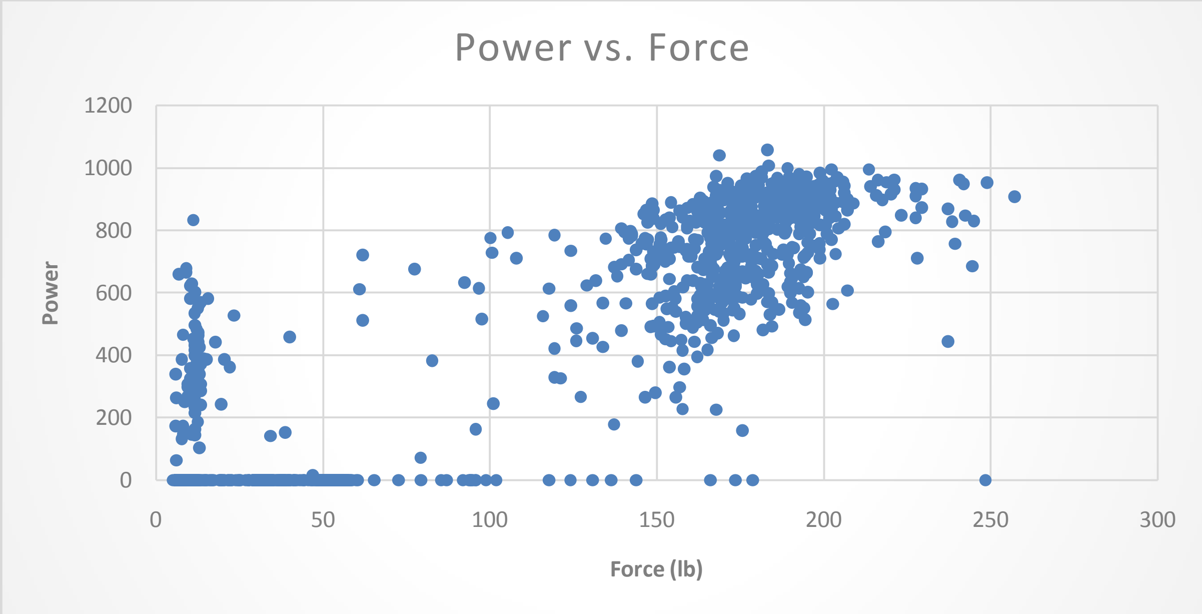
Graph 1. Trial 1, constant braking force.



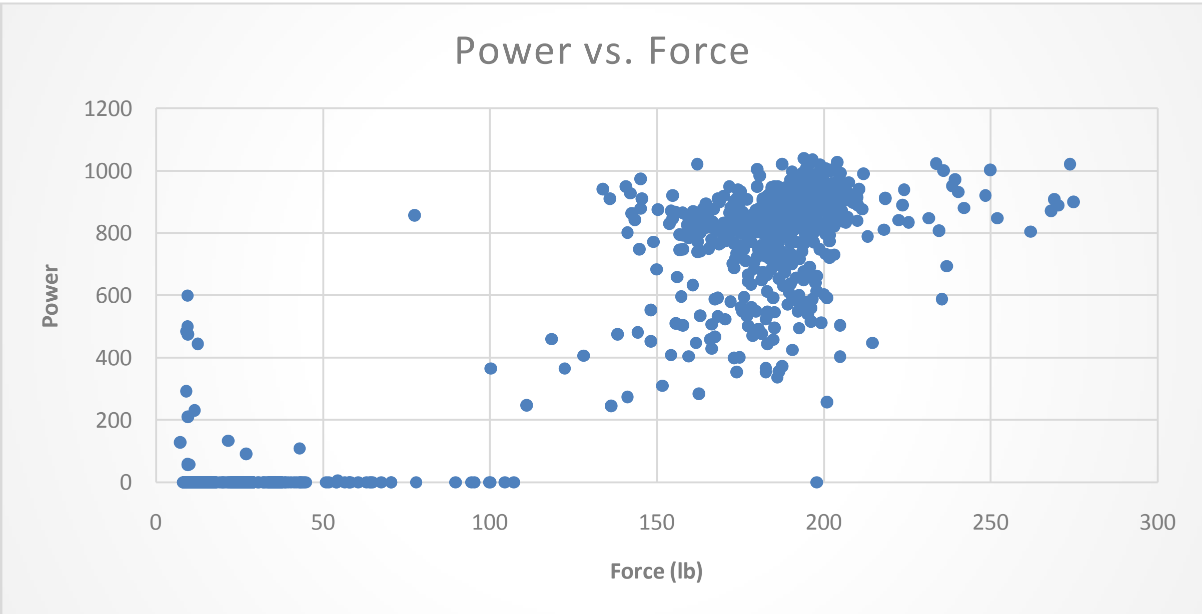
Graph 2. Trial 2, constant braking force.



Graph 3. Trial 3, constant braking force



Graph 4. Trial 4, varying brake force.



Graph 5. Trial 5, varying brake force.

Table 1. Maximum force and corresponding speed for each trial.

Trial	Max Force (lb)	Speed (ft/s)
1	112.47	0.43
2	121.02	0.41
3	128.59	0.40
4	257.31	0.29
5	275.04	0.26

IV. DISUCSSION

The graphs and table from the previous section illustrate the gathered data. Trials 1,2, and 3, with constant braking force, show a gradual increase of power as draft force is increased. A power curve is developed for each trial as all data points are plotted. Within the first three trials, the maximum force developed is approximately 100-120 lb., with 60-80 lb. forces occurring most frequently. During these trials, solid traction was maintained between the AgDrone's tracks and the rough concrete surface. These trials demonstrate the necessity to understand the required force for various farming operations so that a corresponding power can be matched with a small autonomous machine. Draft forces for typical farming operations are displayed in Table 2.

Trials 4 and 5, with varying brake force throughout the test, illustrate a loss of traction rather than a loss of power. During these trials, the AgDrone did not lug down and then come to a stop, but simply lost traction on the rough concrete surface. Once braking force was reduced slightly, traction was regained and the AgDrone was able to continue the pull. This slip occurred multiple times throughout each test. However, increased braking led to a higher maximum force between 200-250 lb. and an average force between 150-200 lb. The AgDrone was able to complete greater force pulls with varying brake forces, which are similar to actual field conditions. Understanding soil and implement interaction is critical in order to develop efficient implements for smaller machines. These trials demonstrated that traction may prove to be more of a challenge than the lack of power. Increasing weight on the AgDrone may be necessary to increase traction and allow for greater forces to be pulled.

Table 1 lists the maximum force along with the corresponding average speed for each trial. In the varying brake force trials, the max force is greatly increased, which decreased the average speed of the AgDrone for both trials. Average speed remained relatively constant during all three constant brake force trials. Decreased speed, but increased pulling ability would allow the AgDrone to perform a greater variety of farming operations. The speed of smaller autonomous vehicles will play a critical role in replacing larger agriculture machinery. Time for each task must be reduced or compensated for with other benefits to make implementation of small autonomous vehicles feasible.

V. ESTIMATED DRAFT FORCES FOR CURRENT FARMING OPERATIONS

Table 2displays the estimated draft forces that would be observed by the AgDrone performing current farming operations while traveling at its maximum speed, determined to be .364 miles per hour. These draft forces were estimated by utilizing the draft requirements equation available in ASABE Standard D497.7[2]. This equation is as follows:

$$D = F_i(A+ B\times S + C\times S^2) \, W \, T \qquad (1)$$

All tillage operations were considered to be primary operations. Both no-till and conventional planting operations were also considered. Medium textured soil was used for each estimation. Tillage depth was assumed to be 6 inches for each tillage operation and a depth coefficient of 1 was used for planting operations as stated by the standard. The machine width was determined to be 2 feet or 1 tool depending on the requirements for the standard. This width was determined to simulate single row operations.

Table 2: Estimated draft forces for AgDrone operating at full capacity utilizing current tillage and planting technology.

Implement	F	A	B	C	Speed (mph)	Implement Width (ft/rows/tools)	Depth (in)	Draft (lbf)
Moldboard Plow	0.7	113	0	2.3	0.364	2	6	952
Chisel (5 cm straight point)	0.85	52	4.9	0	0.364	1	6	274
Sweep Plow (primary)	0.85	68	5.2	0	0.364	2	6	713
Disk Harrow (tandem-primary)	0.88	53	4.6	0	0.364	2	6	577
Dish Harrow (offset-primary)	0.88	62	5.4	0	0.364	2	6	675
Disk Gang (single-primary)	0.88	21	1.8	0	0.364	2	6	229
Field Cultivator (primary)	0.85	26	2.5	0	0.364	1	6	137
Row Crop Cultivator (no till)	0.85	248	19.9	0	0.364	1	6	1302
Row Crop Planter (prepared plant bed)	1	350	0	0	0.364	1	1	350

Row Crop Planter (no till)	0.96	410	0	0	0.364	1	1	394
Grain Drill (press wheels)	1	90	0	0	0.364	1	1	90
Grain Drill (no till)	0.92	160	0	0	0.364	1	1	147
Hoe Drill (no till)	1	420	0	0	0.364	2	1	840
Pneumatic Drill	1	250	0	0	0.364	2	1	500

Based on the data collected and the estimated draft forces for common farming operations, the AgDrone, in its current configuration, would be unable to perform most of the tasks utilizing current tillage and planting technology. The AgDrone can only meet the draft requirements of the grain drill, in both conventional and no-till applications, and the field cultivator. Therefore, changes in farming methods and technology would be required to utilize the AgDrone or a similar system. The AgDrone may also need to be redesigned to increase power production and power delivery to make it a viable replacement for large farm machinery currently used.

VI. CONCLUSIONS

After conducting research and analyzing the collected data from the AgDrone tests, it is illustrated that small scale autonomous machines may prove to be a viable replacement for large agriculture machines. However, additional research needs to be conducted to better match implements and viable power units to produce the most efficient farming operations.

The AgDrone proved successful in pulling forces up to 250 lb. However, this falls short of the average draft force required for typical farming operations. The AgDrone also revealed traction issues that arise when increasing pulling forces. Modifications are necessary to increase traction, which would allow for maximum power output.

Overall, the AgDrone demonstrated that, with modifications and continued research, it may prove a viable replacement for large agriculture machines.

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